The Proceedings of the International Conference on Creationism

Volume 2
Print Reference: Volume 2:II, Pages 101-114

Article 45

1990

Cavitation Processes During Catastrophic Floods

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CAVITATION PROCESSES DURING CATASTROPHIC FLOODS

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ABSTRACT

The destruction of rock by cavitation processes will be examined using a monograph and accompanying software written for evaluating man-made structures. Starting with actual damaging conditions in eight dam structures, the software will be stretched towards examining cavitation potential in simulated natural stream channels during catastrophic flood conditions.

INTRODUCTION

The geologic processes thought to have occurred both during and after the Flood at the time of Noah must have involved the rapid destruction of rock of numerous hardnesses. The erosion processes normally observed today seem too gentle to be the required mechanism. The process of cavitation is examined and found to be a suitably destructive mechanism for flows of shallow, high speed water.

The process of cavitation has been reviewed by Falvey (1) and Holroyd (2,3). Cavitation is the creation of gaseous phase bubbles in a liquid as a result of a decrease in pressure. The creation of bubbles themselves is relatively harmless. If they choke the flow in confined conduits, like tubes, then the blockage is more of a nuisance. It is the collapse of bubbles that can cause structural damage to surfaces that are in contact with the liquid. It will cause powerful shockwaves and possibly minute jets of water that impact the solid surfaces. Though the collapse of bubbles is actually the opposite of the creation of vapor cavities, the term cavitation tends to be used to refer to the entire process.

Cavitation has been involved in the damage of many types of man-made structures. Shock waves and water jets caused by the collapse of cavitation bubbles can clean, dent, or pulverize materials of many types, including concrete and metals. Flow speeds greater than 30 m/s appear necessary for cavitation damage, but thereafter the damage potential can increase rapidly, perhaps at rates proportional to the sixth power of velocity. Major damage can occur with flow depths of only a few meters. Damage initiated by cavitation can provide opportunities to accelerate the rates for normal erosion processes as water plunges into the holes created by cavitation.

Damage potential decreases with flow depth because increasing pressures make it less likely that internal water pressures can be dynamically forced to become less than the water vapor pressure. Cavitation damage is greatly reduced as the air content of the water is increased, suggesting that cavitation damage is unlikely to be found in "white water" rapids. The roughening of water channel surfaces also decreases cavitation damage by slowing the flow speeds and thereby increasing flow depths for constant flow discharge.

A computer model by Falvey (1) predicting damage potential, calibrated qualitatively with actual damages to dam spillways, is used in this study to indicate the locations and relative intensity of damage for several spillway profiles. Those described below include the actual Glen Canyon Dam left spillway, a nearly flat and level surface, and a wide surface having the profile of a small side channel of the Grand Canyon. These studies indicate that the process of cavitation appears to be a likely mechanism for rapid removal of rock in channels having catastrophic flows of high speed shallow water with little air bubble content.

The importance of cavitation in the rapid erosion of rock was physically illustrated during the floods within the Colorado River basin in 1983. After a winter of near-normal snowfall in the basin the snowpack was rapidly increased by spring storms. The record snow pack was then subjected to very warm conditions, causing a rapid melt. In response to the unusual flow of water into the system of dams and reservoirs, water had to be released rapidly from reservoirs to make room for the new water that was soon to arrive. In addition, the height of the Glen Canyon Dam spillway gates, near Page in northern Arizona, was increased by over two meters to create additional storage capacity. These measures were sufficient to limit the damage by the flood waters to the spillway tunnels at that dam.

Water was released past the Glen Canyon Dam through four by-pass tubes, then through the left spillway, and sometimes through the right spillway as well. Flows through the left tunnel began on 2 June, at rates of up to 571 m^3/s (20176 cfs). After about 24 hours at the high rate rumblings were heard from the tunnel. An inspection showed that damage characteristic of cavitation was occurring in the 12.5 meter diameter spillway tunnels. Flows were reduced for about a week, but the coming flood waters necessitated a resumption of high water flows, peaking briefly during a test at 906 m^3/s. Concrete and rocks torn from the tunnel walls could be seen being ejected by the high flows. In late July flows were reduced below 100 m^3/s. Lesser flows were released through the right tunnel during that period.

Later inspection of the tunnels revealed large caverns excavated through the one-meter thick reinforced concrete liner and up to 9 more meters into the sandstone rock. Figure 1 shows a view looking downstream into the largest cavity (10 m deep, 12 m wide, 37 m long). The men and the ladder help provide a scale. Boulders as big as automobiles were excavated by the water from the bedrock and some of them remained in the tunnel downstream of the damage. The largest, which had to have been lifted out of the 10 m deep hole, blocked part of the 12.5 m diameter tunnel. Others are seen in Figure 2, captured from a video (4), at the exit of the tunnel. More illustrations of the dam and damage are given in Holroyd (2).

STUDIES OF CAVITATION PROCESSES

The U.S. Bureau of Reclamation conducted extensive studies to be able to understand the conditions under which cavitation damage might occur, to predict the location and severity of damage, and to design corrections to prevent future damage to water conveyance structures. The studies were then summarized in a monograph by Falvey (1). It thoroughly explores the state of knowledge of cavitation as it relates to the structures typically built and managed by Reclamation. Over 200 references are cited, including work from many foreign countries.

The monograph, giving all relevant equations and some field calibrations, includes a set of 5.25 inch floppy disks of executable programs, source code in FORTRAN, and sample data for use on an IBM compatible microcomputer. One of the programs receives as input a nominated initial flow condition and structural profile. The output is a table of cavitation and flow conditions throughout the structure, and some optional graphs of a few parameters. Other programs provide guidance for profiles having a constant cavitation index, for design of aerator slots for injecting air bubbles into the flow, and for estimating the damage index from a record of historical flow conditions.

Falvey suggests that water heads (indicating the energy available from elevation changes) in excess of about 45 meters and flows in excess of 30 m/s are suspect for the potential for producing damage to structures by cavitation. It was found possible to control the curvature of spillways in the design process so as to minimize the possibility of cavitation damage. But redesigning and modifying structures that were already constructed was potentially too expensive.

The ingestion of air bubbles was found to lower the speed of sound in the water from about 1400 m/s to at or below the speed of sound in air (about 340 m/s). This effect significantly decreases the shock pressure intensities at the solid surface. At about 0.07 moles of air per mole of water, cavitation damage is completely eliminated. Reclamation's solution at the Glen Canyon Dam was to create an air slot part way down the spillway tunnel. After the air slot was made the spillway was tested at water flows greatly exceeding those which caused the damage of 1983. There were no traces of any damage after these tests nor since then.

This effect of air bubbles is of vital importance in dealing with natural water channels. Any channel irregular enough (boulders, ledges, sharp turns) to create "white water" by its turbulence will be unlikely to be damaging its channel bed by cavitation. There will be too much air mixed into the water. It is the high speed clear turbulent flow that is damaging.

UNDERSTANDING THE PROCESS OF CAVITATION

Water boils at that temperature at which the vapor pressure equals the total atmospheric pressure. As the atmospheric pressure is decreased, as at higher elevations, water boils at lower temperatures. Water is usually made to boil by the addition of heat to the liquid. In the process of cavitation water is made to vaporize, like boiling, by instead reducing the atmospheric pressure to below the vapor pressure of water at the temperature of that water.

Bubbles need not be of pure water vapor; other gasses may be present. Gaseous cavitation occurs when cold water is warmed, forcing dissolved air to come out of solution and form bubbles. Gaseous cavitation is also observable when the pressure is reduced by opening a container of a carbonated beverage and bubbles of mostly carbon dioxide are formed. The reduction of pressure as a diver rises from deep water causes the formation of bubbles of nitrogen gas in his blood, leading to the bends.

The pressure at any point within a fluid is the sum of static and dynamic pressures. Static pressure is generally from the weight of all of the fluid above that point, including the atmosphere. Dynamic pressure is the additional contribution, positive or negative, that results from the movement of the fluid. Positive dynamic pressure is like the pressure of the wind or of water flow against a stationary object. Negative dynamic pressure occurs, for example, in the air above the curved wing surface of an aircraft and causes it to fly. Ship propellers are subject to damage by cavitation on the fore side because of decreased dynamic pressures there. Dynamic pressure decreases resulting in cavitation damage also occur in water valves, pumps, and gates that regulate the flow of high speed water.

DAMAGE FROM CAVITATION

The bubble formation itself does not create the damage of cavitation. It is the downstream collapse of those bubbles, where pressures are restored in excess of the vapor pressure, that can subject solid surfaces to shock waves and water jet impacts. Falvey summarizes two methods that may be involved. Bubbles that collapse within the water send out shock waves. As these shock waves encounter another bubble, they subject it to a pressure increase that is likely to cause the collapse of that bubble as well. The newly collapsed bubble adds its energy to the shock wave. In this manner the bubbles collapse in phase and together create a shock wave of large amplitude. When the shock wave produced by the collapsing bubbles reaches a solid surface, even if there are no bubbles there, they strike the surface with a considerable force. The present theory suggests that the magnitude of the pressures that are generated can exceed 200 times ambient pressure.

The other mechanism for damage is for bubbles in contact with a solid surface when they collapse. The contact gives the bubbles a slight to major asymmetry. The dynamics and wave mechanics of the collapse cause a water jet to be initiated on the bubble surface opposite the solid surface. That tiny jet then strikes the side of the bubble in contact with the solid surface. Such jets have pitted aluminum with a yield strength in excess of 300 MPa, or 3000 times normal atmospheric pressure.

Falvey gives some preliminary indications of the relative strengths of some materials in terms of the amount of time to achieve the same amount of damage from cavitation. The relative scale gives concrete--1, polymer concrete--42, aluminum or copper--80, carbon steel--286, stainless steel--2000. Some values for granite, sandstone, shale, and limestone would have been desired, but the concrete value might approximate that for limestone.

There are three numbers among the equations of Falvey that are used to describe several aspects of the cavitation process: the cavitation index, the cavitation damage potential, and the damage index. Only the damage potential will be discussed here. It addresses the question, given that cavitation is likely to occur at a location, of how strong the damaging forces will be. The damage potential was crudely calibrated by Falvey by comparing actual damage at several dams with the theoretical damage potential numbers. He gives values of damage potential for "incipient", "major", and "catastrophic" damage as 500, 1000, and 2000, respectively. The damage at Glen Canyon Dam was considered to be "catastrophic".

LOCATING THE CAUSES FOR CAVITATION

The Falvey monograph summarizes theoretical cavitational characteristics for a variety of general flat and curved profiles of water channels. Concrete structures do not remain smooth, even if so constructed. There may be displacements along joints, calcite deposits, and craters changing the surface by a variety of mechanisms. While bumps in a smooth surface are likely origins for cavitation, it was found that uniform roughness could create a thicker boundary layer and decreased flow speed at the bumps that would ordinarily initiate damage.

Cavitation damage can be recognized by its texture, locational symmetry, and origin, as described by Falvey. Cavitation damage always occurs downstream of its cause and never propagates upstream. Surface irregularities that cause cavitation are left intact and can be inspected upstream of the damaged area. Cavitation damage created by longitudinal vortices will not have exact origins, like surface bumps, to identify them.

A bump (it can also be an offset into or away from the water stream) initiates cavitation damage by creating a flow disturbance that results in a dynamic pressure decrease sufficient to create bubbles, as illustrated in Figure 3. These bubbles collapse downstream and damage the nearby surface. Prolonged damage produces another flow disturbance, more bubbles, and more damage. The surface downstream of a bump can thereby develop a chain of craters. A series of holes about 3 meters deep and 6 meters wide was the form of the damage upstream of the largest hole in the Glen Canyon Dam left spillway.

Once a hole is started by cavitation, the flow of water begins to be diverted into the hole. High velocity water will impinge on the downstream end of the hole, creating higher pressures there compared to the ambient pressures. The high pressure water typically finds minute cracks and forces them to enlarge. The destructive process then changes from cavitation to normal erosion as large chunks of material are ripped out of the surface of the water channel. Whereas pitting from cavitation tends to be at random locations, erosion tends to be more organized and striated.

COMPUTER SIMULATIONS

The Falvey software presents theoretical cavitation characteristics for a variety of flat and curved profiles of water channels, surface rugosities, flow depths and speeds, and several sizes and shapes of flow disrupters. Some of the programs describe and graph the flow and cavitation conditions for any nominated profile and initial flow conditions. The software has been run for over twenty Reclamation-designed dams and others throughout the world. The software is currently able to predict locations of cavitation damage with high reliability. Though more research and calibration is probably in order, the present computer model can be considered to be approximately calibrated for real flow conditions. Its outputs are in good agreement with observations. The limitations of the software are reviewed by Holroyd (3).

The "catastrophic" flows through the Glen Canyon Dam drainage tubes were small compared to flows that those interested in catastrophic geological processes would like to consider. Therefore the software was used to explore greater magnitudes of flows. The Glen Canyon left tunnel model was subjected to flows from so low that the software complained of analysis difficulties up to the limit of the design capacity of the tubes. Then the left tube profile was retained but the cross section, width, approach and exit characteristics were changed and the flows were varied again from the lowest to the highest that the software would accept. Such variations on the Glen Canyon profile showed that the model could be extrapolated into conditions unlikely to be experienced today. The integrity of the results during such changes gave confidence that the next modifications to artificial and natural profiles would give reasonable results. In this way there was an orderly progression from known cavitation conditions to those far beyond present day experiences.

THE GLEN CANYON LEFT SPILLWAY SIMULATIONS

The program was stepped through an orderly series of initial depths with the flow rate carefully adjusted to produce initial speeds of 5, 10, and 20 m/s at the top of the spillway. The water rapidly accelerates as it falls down the spillway. After passing the 700 m mark (from an upstream reference point) the tube bends to the horizontal (starting about 800 m). The sudden transition between the centrifugal pressures of the curved profile and the nearly static pressures of the horizontal flow produces a forward acceleration and suddenly higher velocities there. It is also the location of the shallowest flow and deepest damage.

The damage potential over the length of the spillway is graphed in Figure 4 as a function of initial flow depth. In this and following figures the surface perturbation consists of a 10 mm (1/2 inch) circular arc. At that size the damage potential is nearly proportional to the size of the bump. The rugosity value was that for very smooth concrete. For this and the other figures the damage potential contours are given number labels, n, on a logarithmic scale, where the damage potential is 1000 x 2^n. With this coding a -1 is for "incipient" cavitation, 0 for "major" and 1 for "catastrophic". A number of 11, to be seen in the next figure, would then indicate a damage potential 1024 times larger than that of the 1983 Glen Canyon Dam flows.

At the top of the graph for the 5 m/s initial speed the actual cavitation damage, in terms of relative depth, is shown by the shading. At the left of all three parts of the figure are shown indicators for the initial flow depths corresponding to 300 (strong), 600 (high), and 900 (peak) m^3/s flow rates. The Falvey monograph does not give the initial flow speeds for the historic flow rates. The failure of the computer program to model the higher flow rates at the 5 m/s speed suggests that the actual speeds might have been between 10 and 20 m/s.

For later comparisons the 10 m/s initial speed was selected as a reasonable value.

Cavitation damage is not the same as damage potential. Though there was only one major peak of damage near the 800 m location, the curves of Figure 4 indicate two peaks for damage potential, at the start and end of the circular transition from near vertical flow to near horizontal flow. Damage potential is greatly reduced in the circular bend because the centrifugal forces produce larger pressures, making cavitation less likely. Of all of the dam profiles tested by the Bureau of Reclamation with this program, only the upper peak in damage potential in the Glen Canyon Dam spillway failed to be actualized. Furthermore, while there is less damage potential in the circular bend than in the transitions on either end, damage still occurred there. A change in the simulations from smooth concrete to a rough concrete surface (not shown) decreased the calculated damage potential.

Figure 4 also illustrates some of the theoretical behaviors discussed in Falvey (1) and reviewed in Holroyd (2). The shallow initial flow depths produce even shallower depths downstream. Friction limits the speeds of the shallow depths of water and therefore causes the steep gradient of damage potential with depth for initial depths of less than 2 meters. The 20 m/s diagram shows that increasing initial depth actually decreases the damage potential because increasing depth increases static pressure and makes it more difficult for dynamic pressure reductions to reach values at which water will vaporize. The effect of increasing initial depth on decreasing cavitation damage potential is especially strong in the circular curvature section between 700 and 800 meters, where centrifugal forces add to the static pressure. This is a strong reminder that great depths of water will not cavitate. An ocean of water traveling across land at high speeds may be quite destructive, but it will not be by cavitation.

THE SEMI-HORIZONTAL SIMULATIONS

The possibilities of cavitation over nearly flat terrain were then examined. Input width was changed to 1 km and a simple profile was designed which consisted of 5 km of nearly flat terrain having a constant slope of only 0.004. Then, to drain the water away from the semi-flat region, the terrain was given a parabolic profile matching the free fall arch of an object traveling horizontally at 500 m/s. Initial flow speeds of up to 100 m/s were used in the simulations and the conditions in the parabolic section were ignored. The water was always decreasing its speed over the semi-flat portion and therefore increasing its depth to maintain a constant flow.

Numerous computer runs were made in order to map out the damage potential in Figure 5. In this figure it is the actual water depth that is the ordinate and the actual flow speed for the abscissa rather than the initial conditions. The logarithmic coding of the damage potential is again used. The solid lines give the locations of the calibrated "incipient, major, and catastrophic" conditions and the dotted lines the extrapolated values.

It is seen that significant damage potential begins with shallow flows of about 30 m/s. It increases rapidly with flow speed, remembering that the contour lines differ by a factor of 2. It is also seen that the damage potential decreases with increasing flow depth. This is because the increased ambient pressure caused by greater depths makes it harder for dynamic pressure fluctuations to reduce to the vapor pressure of the water.

In creating this figure, no consideration was made as to how such speeds might be achieved. The rapid reduction of speed with downstream distance that appeared in the simulations indicates that viscosity and friction will prevent high speeds from being sustained at a slope of 0.004. Yet Figure 5 indicates that if there is some cause for water to exceed a speed in excess of about 30 m/s, then cavitation damage potential exists for even semi-flat terrain. The nearly flat terrain of this simulation was especially designed to produce a simplified diagram in which the speed threshold of cavitation damage potential and the normally inverse relationship of flow depth to damage potential were readily evident.

THE PAPAGO CREEK (GRAND CANYON) SIMULATIONS

A natural channel was then chosen to see if there were any conditions under which cavitation would occur if various flows of water were allowed to follow such a profile. In order to get depth and variety, a steep and generally straight side channel of the Grand Canyon of Arizona was chosen. The profile was along a line parallel to Papago Creek (about 36^{o} 2'N, 111^{o} 54'W), from the highway towards Solomon Temple, at an azimuth of 333^{o}. The horizontal distance was the distance of the contours from the highway, not the integrated distance along the twisting channel. The resulting profile of the cross section is shown in the upper part of Figure 6. The elevations were taken from a 1:62500 scale topographic map of 80 foot contour interval. Though nearly 60 contours were available, only 40 could be used in the model. So 160 foot contours were used initially and then supplemented by 80 foot contours in sections (generally flat) recommended by the software.

Though the coded contours of damage potential are not always resolvable in this reproduction, what is important is their density and location. The middle drawing has rugosity and initial conditions comparable to those in Figures 4 (middle) and 5. Yet in many locations the damage potential equals or greatly exceeds that for the Glen Canyon Dam spillway profiles. The curve labeled 8 indicates a damage potential exceeding 100 times the conditions observed in the 1983 floods. The lower part of Figure 6 is probably more realistic for a natural channel roughness. Yet it also indicates the possibility of equal or greater damage from cavitation than observed in 1983 at the Glen Canyon Dam.

The water depths were not increased to the level beyond which the cavitation potential would decrease. The cliff-like portions of the profile made the software issue complaints for depths greater than those illustrated.

Comparing the upper and lower parts of Figure 6 gives an indication of which parts of the profile are likely to cause cavitation damage. The highest damage potential occurs where water would encounter a negative radius of curvature for the surface. This condition reduces the ambient pressure (weight of the water above a point) much like a vehicle traveling over the same profile experiences a tendency towards weightlessness. But such locations can also inject air into the water stream if they are cliff-like, such as the Redwall limestone near the 1 km location.

Other locations for enhanced damage potential are where the water has a great speed from a recently rapid drop in altitude. On the other hand, the reduced damage potential from 2 to 3 km results from reduced speeds and increased flow depths caused by the more level terrain. In general, the damage potential is greatest where there are steep drops in the stream profile. This suggests that the heads of canyons can experience rapid removal of rock as a result of cavitation processes if such large flows of water spill into them without much ingestion of air.

The choice of Papago Creek was made to find out what a variety of rock strata would do, as represented by present profiles. Hard rocks will have semi-horizontal top surfaces and cliff-like edges. Softer shales will have intermediate slopes. If a large flow of water was to pass over the cliff edge in such an environment without ingesting much air, then damage initiated by cavitation is likely to occur. The choice of Papago Creek was for convenience. It does not indicate any suggestion that a large flow actually occurred in that location. There is presently no way such a flow of water could arrive at the cliff edge and the size of the headwaters is trivial. However, the hardnesses of the rocks during the carving of the Grand Canyon might have been similar to those observed today and reflected in the present erosion profile. A catastrophic flow of water, such as might result during the capture of the Colorado River through the Kaibab uplift, might encounter similar profiles. This computer simulation shows that there are indeed locations for cavitation processes to greatly accelerate the removal of rock.

DISCUSSION AND CONCLUSIONS

As considered in this paper, cavitation is the creation of water vapor bubbles within liquid water by the reduction of pressure to the vapor pressure of water at the temperature of that water. The term cavitation has been erroneously extended to include the damaging processes associated by the collapse of those bubbles.

The process of cavitation damage relating to water conveyance structures was explored with the help of a monograph on cavitation and the accompanying software packages. Variables of particular importance during the process of cavitation are the head of water (available energy from elevation changes), water depth and speed (affecting the static and dynamic pressures), water temperature (affecting the vapor pressure), surface roughness, material strength, and especially air bubble content. The software, qualitatively calibrated by assessments of historical damage to existing spillways, was used to map flow and cavitation conditions for the Glen Canyon Dam left spillway tunnel. After documenting the software behavior for known damage, the programs were used for other simulations. That for wide, nearly flat, terrain illustrated the effects of water speed and depth on the cavitation process. It indicated that cavitation damage should be suspected for flow speeds greater than 30 m/s in shallow water. The simulated spill of water over the rim of the Grand Canyon indicated a potential for greater cavitation damage to the rock than the greatest damage observed in the 1983 floods.

The purpose of these initial simulations was to examine the cavitation process for a few profiles during conditions of water flow much greater than modern science has measured.

Though the monograph labeled the 1983 Glen Canyon Dam spillway damage as "catastrophic", the software was pushed to damage potentials over 100 and 1000 times as great. The software cannot be calibrated for those conditions, but it still gives guidance for such extremes. As expected, flows in excess of those observed in 1983 can be expected to produce damage much more severe than that which created automobile-sized boulders out of sandstone bedrock during a several-week period. It suggests that greater flows of water might have the potential for carving canyons even in hard rocks in several weeks rather than the slower thousands-of-years rates observed with normal erosion processes. Yet the simulations also showed that damage potential eventually decreases with increasing water depth. Water depths cannot exceed a few tens of meters or else cavitation will cease.

This has been only an initial exploration of cavitation with software simulations. The variety of possible input conditions is practically infinite. There is much opportunity for further research into numerous phenomena related to the process of cavitation. The software can be run on many natural profiles for water channels to explore the range of profiles and water flows that might lead to cavitation conditions. Of particular interest might be scenarios of catastrophic drainage of post-glacial lakes. There are several canyons which, if plugged, would support vast lakes upstream of them. A breaching of the dam, a natural ridge holding back the lake waters, could involve water speeds sufficient to initiate cavitation damage.

But even with the present knowledge and actual experience it appears that the rapid destruction of rock by the process of cavitation can greatly assist the process of normal erosion in removing rock from water channels during truly catastrophic flows of water. Thousands or millions of years are not necessarily needed for the carving of some valleys and canyons if the process of cavitation becomes involved.

ACKNOWLEDGMENTS

Parts of this study were funded by the Creation Research Society Laboratory Project, 1306 Fairview Road, Clarks Summit, PA 18411.

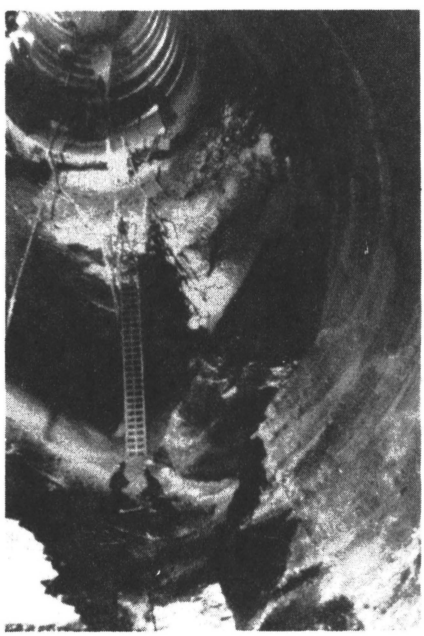

Figure 1. A view of the greatest cavitation-initiated damage in the left spillway tunnel of the Glen Canyon Dam, near Page, Arizona. The tunnel diameter is 12.5 meters; the ladder into the 10 m deep hole and the workmen provide additional scales. (Bureau of Reclamation photo)

REFERENCES

(1) Falvey, Henry T., CAVITATION IN CHUTES AND SPILLWAYS. Bureau of Reclamation, Denver, Colorado. 1990 (in press).

(2) Holroyd, Edmond W., III., "An Introduction to the Possible Role of Cavitation in the Erosion of Water Channels", CREATION RESEARCH SOCIETY QUARTERLY, Vol. 27, 1990, (accepted).

(3) Holroyd, Edmond W., III., "Some Simulations of the Possible Role of Cavitation in Catastrophic Floods", CREATION RESEARCH SOCIETY QUARTERLY, Vol. 27, 1990 (accepted).

(4) "Challenge at Glen Canyon", 27-min video, Bureau of Reclamation, Denver, Colorado, 1984

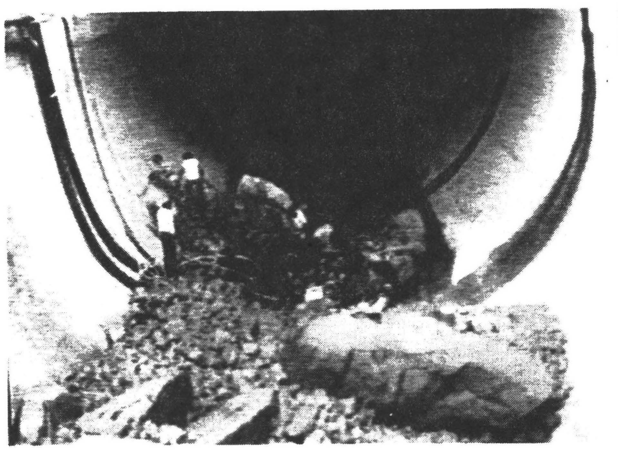

Figure 2. Large boulders were excavated by the water and deposited at the end of the left spillway tunnel. The 12.5 meter diameter of the tunnel and the workmen provide a scale. (from Bureau of Reclamation video)

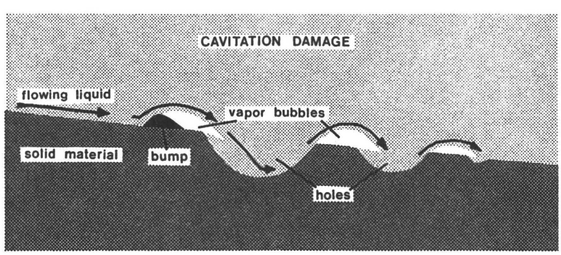

Figure 3. Cavitation damage can occur to a solid surface by the formation and collapse of vapor bubbles downstream of a bump. Large holes can cause more downstream cavitation and damage.

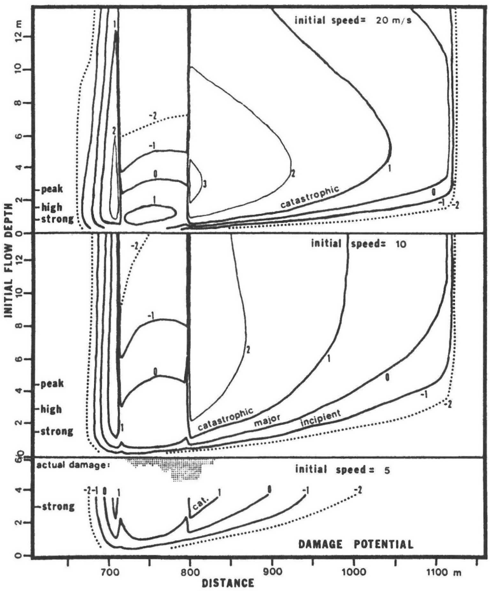

Figure 4. The damage potential for the Glen Canyon Dam left spillway tunnel as a function of initial depth. The damage potential is labeled in terms of powers of 2 times "major" cavitation damage potential.

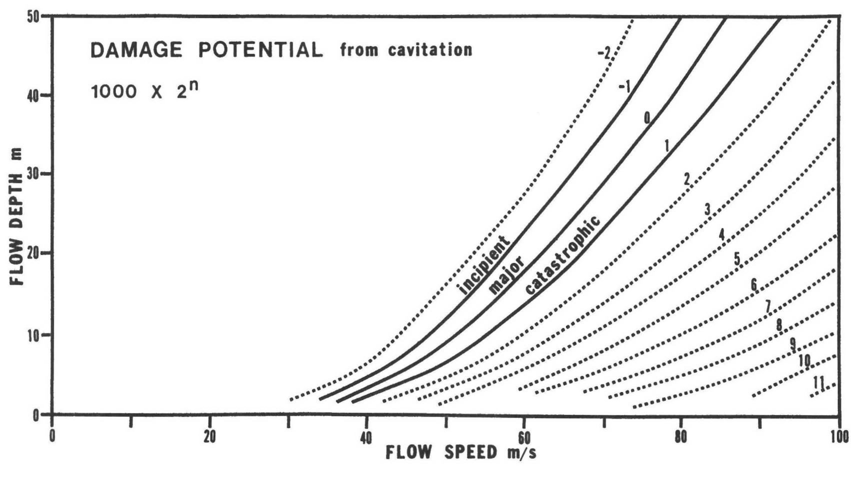

Figure 5. The damage potential for nearly flat terrain for actual, rather than initial, flow depths and speeds.

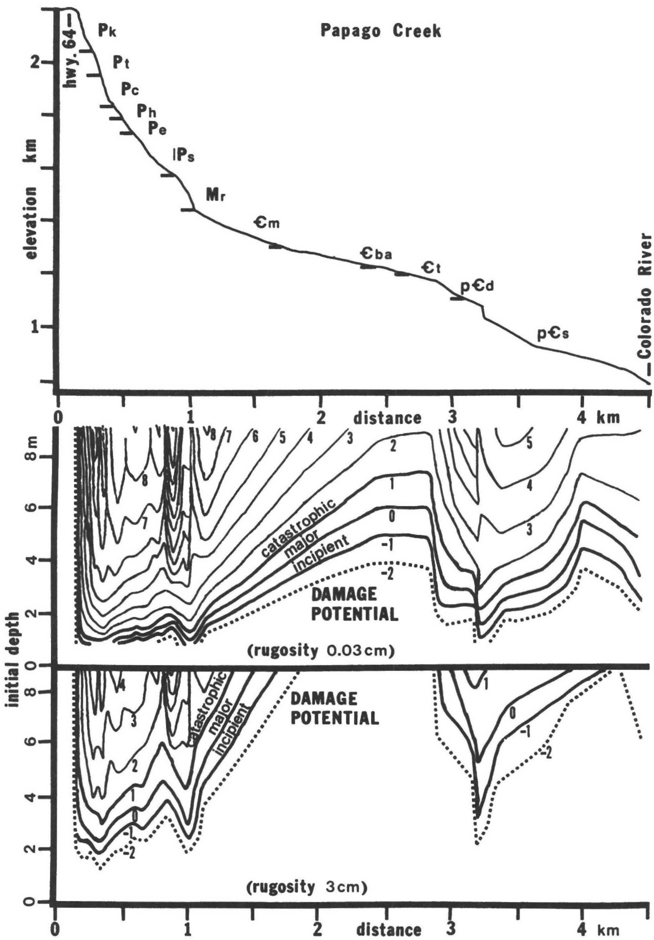

Figure 6. (Top) The vertical profile of Papago Creek and the geological strata exposed. (Middle and Bottom) The damage potential as a function of initial depth for a 1000 ft wide Papago Creek profile for 10 m/s initial flow speed. The middle curves, coded as in previous Figures, are for a smooth surface and the bottom curves are for a rough surface.

DISCUSSION

Dr. Holroyd is helping perpetuate the vision of the vast potential that cavitation related damage has for explaining a vast restructuring of much of the crust of the earth during and after his Historical Flood. I believe the use of the title Historical Flood is justified because of the 200+ widely separated flood records, legends, oral traditions, myths, etc., that are obviously referring to the same event recorded most thoroughly and accurately in genesis 6-9. It is also referred to by Christ in matthew 24, and elsewhere by Christ and many other recorders of history in the Bible and other sources. Also that term should blunt the anti-Biblical bias so pervasive and unfortunately growing in our culture.

Dr. Holroyd makes very good use of the Bureau of Reclamation accumulated history of cavitation damage collected, summarized and computerized by Dr. Henry T. Falvey. Fortunately the Bureau and others have learned how to preclude cavitation damage to many man made structures. The short time duration of their tests prove that they know from experience how rapidly cavitation bubble collapse can erode strong materials. the fact that potentially catastrophic floods can be caused at dams does focus attention on the continuing studies at dams where constant monitoring and exact dimensions are available.

The availability of a computer model provides means for widespread efficient study of cavitation potential. The realistic possibility of the Grand Canyon having been formed in a short time is greatly enhanced by the Papago Creek Model suggested by Dr. Holroyd.

I would like to see studies of flow velocities from unrestrained tides for nearly a year over much of the submerged land forms combined with the resultant cavitation and erosion forces and have the magnitude for erosion estimated. Along with that I ask the question: Where was the material that makes up the upper 95% of the mile thick sedimentary layer when the lower 5% was being deposited? Another related question: What would result from a broad spectrum of fluid specific gravities causes by intense cavitation and erosion activity over a year and how would it settle out as flow velocities gradually decreased?

Dr. Holroyd has made a major contribution in adjusting the focus knob and improving our viewing of the potential from cavitation and related forces for a quick restructuring of much of the crust of the earth during and after the Historical Flood.

The likelihood that the Chernobyl disaster was caused by inadequate knowledge about cavitation should certainly cause a quantum leap in the search for all possible information about cavitation.

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As ambient fluid hydrodynamic pressure increases, hydrostatic pressure decreases; if hydrostatic fluid pressure falls below fluid vapor pressure (at a given temperature), bubbles may form at the point of minimum hydrostatic (maximum hydrodynamic) pressure.

P_o = Fluid Static Pressure

P_V = Fluid Vapor Pressure

C = Fluid Density

V_T = Fluid Total Velocity

V_I = Initial Velocity

$$\frac{(P_o - P_V)}{\frac{1}{2} C V_T^2}$$

$$V_T = V_I \sin\theta$$
$$@\ G = 90^\circ$$

V_T = Maximum Dynamic Pressure, minimum static pressure

Dr. Holroyd seems to indicate that *decreased* dynamic pressure results in cavitation (pg.3 Para 2); this is only correct if by "cavitation damage" he is not referring to "initiation" of cavitation (formation of bubbles), since this phenomenon occurs in regions of maximum dynamic pressure. It is true that in regions of least dynamic pressure and max static pressure, the bubbles will implode. Cavitation damage will occur if a rock surface is in close proximity to implosion-generated spherical shock waves. Damage proximity is in accordance with $\left(\frac{1}{r^2}\right)$ from spherical shock front origin.

Critical to any discussion of cavitation are the parameters of

- * Cavitation initiation zone
  - —max dynamic pressure
  - —minimum static pressure
- * Cavitation surface reduction zone
  - —minimum dynamic pressure
  - —max static pressure

1- Note that the pressures (static and dynamic) are exactly opposite for cavitation initiation and reduction (damage). In my opinion Dr. Holroyd does not present this adequately, the differentiation of the two unique environments are very vague in his paper.

2- He should definitely include the cavitation number:

$$\sigma = \left[\frac{(P_{\text{Ambient}} - P_{\text{Vapor}})_{\text{Static}}}{\frac{1}{2} C^{V^2_{\text{Total}}}}\right]$$

The probability of cavitation *initiation* varies inversely proportional to sigma.

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CLOSURE

Reply to Mr. Paul MacKinney

When pondering possible scenarios in which cavitation might be a mechanism for the rapid removal of rock, several factors must be remembered. An energy source must be available to accelerate the water to speeds in excess of 30 m/s. This can be provided by a water head in excess of 45 m. The water must be shallow because depths greater than 10 m cause static pressures greater than 2 atmospheres against which dynamic forces must operate to vaporize the water. Hot water will cavitate at higher pressures than cold water. Air bubbles in the water, ingested by stream turbulence, greatly reduce the possibility of cavitation. Cavitation will not be a significant mechanism in rough mountain streams and in deep bodies of water.

Further research needs to be done on the relative strengths of various rocks against the forces of cavitation. Perhaps there is someone with mountain stream property that will support a penstock about 50 m (150 ft) tall, from which water can be directed to flow across large rock samples. Such an outdoor laboratory would need to be properly engineered to withstand the forces involved.

Computer simulations can be performed on a variety of natural channels. The sudden drainage of the glacial waters of Lake Missoula across the channeled scablands of central Washington provides a possible simulation scenario. A mountain river flood possibility is the 1976 Big Thompson Canyon flood. If the simulations indicate that cavitation was a possibility, then the river channel can be examined for evidence of rapid destruction of rock. Similarly, tall waterfall regions can be examined to see if cavitation is not operating where water heads and speeds are sufficient for the process.

Those individuals who have already taken up the study of the cavitation mechanism should not be relied on for all future research. Additional workers are needed to bring new insights and clarifications on the rapid destruction of rocks during catastrophic floods. Perhaps some readers will be inspired to study the physics and join the research.

Reply to Mr. Clifford Paiva

This paper is a brief summary of the two CRSQ references, of 10 and 7 pages each, which themselves contain brief summaries of the 145 page Falvey monograph. Mr. Paiva did not have access to any of these at the time of his review. The misunderstandings partly result from the summarization process which lead to the intentional absence of equations in this ICC version. The rest appears to come from style and notation differences.

Mr. Paiva's initial expression is of the same form as his final equation for the cavitation number. Falvey and I give this equation in our referenced works, but we name it the cavitation index instead. We differ from Paiva in that his "total velocity" term is a reference velocity in our expressions, measured at the same up-stream point as the reference pressure term in the Bernoulli equation.

Neither Dr. Falvey nor I make any sinusoidal assumptions for the form of the velocity term. In the equivalent expressions, ours are reference velocities at an upstream point and are therefore understood to be constant for a given flow. Though Mr. Paiva makes no explanation for his sinusoidal expression, it would seem to allow counterflows, moving upstream against the current with speeds up to the maximum downstream speed.

My understanding of Dr. Falvey's use of pressure is that it is the same as the pressure term in the Bernoulli equation and therefore distinct from the velocity term. For constant elevation (no total energy changes) the Bernoulli equation shows pressure changes to be of opposite sign to changes in the square of the velocity. Furthermore, my understanding is that the pressure term is the sum of static and dynamic pressure components. The static pressure is simply that resulting from the weight of all fluid and atmosphere above the level of measurement. The dynamic pressure is caused by changes in velocity and can reduce or add to the total pressure, as measured by a gauge. Both Dr. Falvey and I use an absolute pressure scale.

Mr. Paiva's P is an ambient static pressure only. He appears to call his velocity term the dynamic pressure, such that the greater the velocity, the greater the dynamic pressure. This results in an opposite sign from ours. Our sense follows the Bernoulli equation, whereby an increase in speed results in a decrease in pressure, as over an airplane wing.

A better understanding of the theory of cavitation processes can be obtained from a study of the Falvey monograph rather than from my summaries.

Edmond W. Holroyd, III, Ph.D.